UTCCP-P-76

# Heavy-light spectrum and decay constant from NRQCD with two flavors of dynamical quarks*

CP-PACS Collaboration : A. Ali Khan[a], S. Aoki[b], R. Burkhalter[a,b], S. Ejiri[b], M. Fukugita[c], S. Hashimoto[d], N. Ishizuka[b], Y. Iwasaki[a,b], K. Kanaya[a,b], T. Kaneko[a], Y. Kuramashi[d], T. Manke[a], K. Nagai[a], M. Okawa[d], H.P. Shanahan[e], A. Ukawa[a,b] , and T. Yoshié[a,b]

[a]Center for Computational Physics, University of Tsukuba, Tsukuba, Ibaraki 305-8577, Japan

[b]Institute of Physics, University of Tsukuba, Tsukuba, Ibaraki 305-8571, Japan

[c]Institute for Cosmic Ray Research, University of Tokyo, Tanashi, Tokyo 188-8502, Japan

[d]High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan

[e]DAMTP, 21 Silver St., University of Cambridge, Cambridge, CB3 9EW, England, U.K.



We report on a study of $B$ mesons on $N_f = 2$ full QCD configurations using an RG-improved gauge action, NRQCD heavy quark action and tadpole-improved clover light quark action. Results on the heavy-light spectrum and the decay constants from $16^3 \times 32$ lattices at $a^{-1} \approx 1.5$ GeV are presented, and compared with quenched results obtained with the same action combination at matching lattice spacings.

## 1. Introduction

The decay constant $f_B$ is being studied extensively on the lattice because of its importance for the determination of CKM matrix elements. The spectrum of excited $B$ mesons and $b$ baryons is being measured in present experiments, whereas there exist only few lattice results on this subject.

In this article we report on our study of $B$ mesons in two-flavor full QCD employing the NRQCD action for heavy quark and a tadpole-improved clover action for light quark. The dynamical configurations have been generated using the same light quark action and an RG-improved gauge action with a plaquette and a rectangular term. Details on our full QCD configurations can be found in Refs. [1]. A parallel study of $B$ mesons using the clover action for heavy quark is presented in Ref. [5].

## 2. Simulation Details

We present results for two sets of dynamical lattices corresponding to the heaviest and the lightest sea quark in our configuration set at $\beta = 1.95$. The results are compared to those from quenched lattices generated with the same RG-improved gauge action at $\beta = 2.187$, the lattice spacing from the string tension matched to the dynamical lattice with $\kappa_{sea} = 0.1375$. Some details on these runs are given in Table 1.

Table 1
Parameters of lattices. The statistics for the dynamical lattices has been increased since Lattice'99. The scale is fixed by $\sqrt{\sigma} = 427$ MeV (for each sea quark for dynamical configurations)

| $\kappa_{\rm sea}$ | 0.1375 | 0.1410 | $\infty$ |
|---|---|---|---|
| $m_{PS}/m_V$ | 0.8048(9) | 0.586(3) | – |
| $a_\sigma^{-1}$[GeV] | 0.937(6) | 1.127(10) | 0.919(7) |
| #conf. | 648 | 490 | 195 |

We take 5 $\kappa$ values for the light valence quark corresponding to $m_{\rm PS}/m_{\rm V} \approx 0.8 - 0.5$. The strange quark mass $m_s$ is fixed using the $K$ and the $\phi$ meson. Our results for the $B_s$ meson are obtained with $m_s$ from the $K$, and the $\phi$ is used to estimate the systematic error.

*talk presented by A. Ali Khan

Table 2
Results for decay constants. Errors given in this table are statistical (including the statistical uncertainty in $M_b$), and, where applicable, the uncertainty in fixing the strange quark mass. Other systematic errors are discussed in the text.

| $\kappa_{\rm sea}$ | $f_B$[MeV] | $f_{B_s}$[MeV] | $f_{B_s}/f_B$ |
|---|---|---|---|
| $\infty$ | 193(4) | 221(4)(+7) | 1.147(10)(35) |
| 0.1375 | 216(4) | 250(4)(+8) | 1.157(9)(+35) |
| 0.1410 | 215(6) | 251(6)(+6) | 1.166(14)(+31) |

For the heavy quarks, we use NRQCD at $O(1/M)$ with a symmetric evolution equation as defined in [2]. We employ 5 bare heavy quark masses, covering a range of roughly 2.5 − 4.5 GeV.

The heavy-light meson mass $M$ is determined from the difference of the meson energy at finite momentum and at rest, assuming the dispersion relation, $E(\vec{p}) - E(0) = \sqrt{\vec{p}^2 + M^2} - M$. As a consistency check, we use both the $B_d$ and the $B_s$ meson to determine the b quark mass.

In our calculation of decay constants, the heavy-light current is corrected through $O(\alpha/M)$. The mixing coefficients between the lattice operators [2] contributing at this order to the time component of the axial vector current $J_4$, and the matching factor to the continuum current has been calculated [3] in one-loop perturbation theory,

$$J_4 = (1+\alpha\rho_0)J^{(0)}_{4,lat} + (1+\alpha\rho_1)J^{(1)}_{4,lat} + \alpha\rho_2 J^{(2)}_{4,lat}. \quad (1)$$

For the RG-improved gluon action, $\alpha_V$ has not been calculated, and we use a tadpole-improved one-loop expression for the $\overline{MS}$ coupling, $\alpha^{TI}_{\overline{MS}}(1/a)$.

## 3. Decay Constants

Our preliminary results for $f_B$, $f_{B_s}$ and $f_{B_s}/f_B$ are given in Table 2, along with the statistical error and, where applicable, the uncertainty in the determination of $m_s$. Additional systematic errors are estimated as follows: $O(\alpha^2)$ corrections, taken to be $\alpha^2 \times O(1)$, are 5%. A previous NRQCD calculation using the plaquette gluon action at $a^{-1} \sim 1$ GeV finds the tree level $O(1/M^2)$ corrections to be $\sim 2\%$ [4]; we estimate our error from the truncation of the $1/M$ expansion to be $\sim 4\%$. The leading discretization effects from the light quarks and gluons of $O(\alpha a \Lambda_{QCD})$ and $O(a^2\Lambda^2_{QCD})$ are 5%. Added in quadrature, these estimates give 7%.

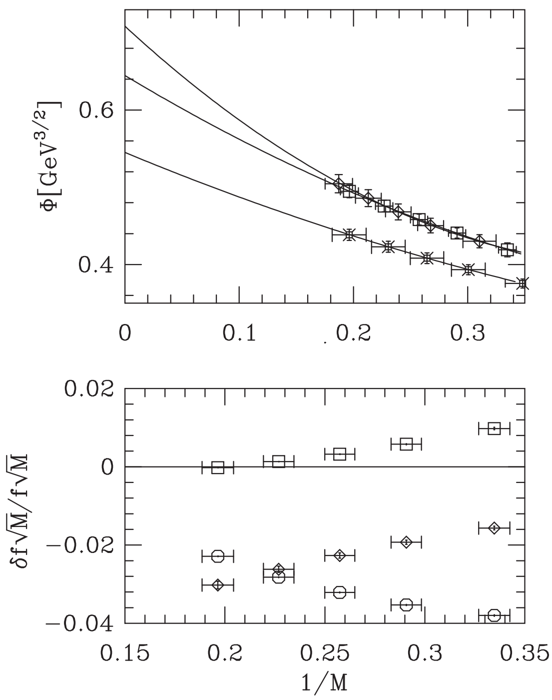


Figure 1. $\Phi \equiv (\alpha_s(M)/\alpha_s(M_B))^{(2/\beta_0)} f\sqrt{M}$ (top), and one-loop corrections to $f\sqrt{M}$ (bottom) as a function of the inverse pseudoscalar meson mass. In the upper plot, squares stand for $\kappa_{\rm sea} = 0.1375$, diamonds for $\kappa_{\rm sea} = 0.1410$ and fancy squares for quenched. In the lower plot, circles denote $\alpha\rho_0 J^{(0)}_{4,lat}/J_4$, squares, $\alpha\rho_1 J^{(1)}_{4,lat}/J_4$, and diamonds, $\alpha\rho_1 J^{(2)}_{4,lat}/J_4$.

Our two-flavor results for $f_B$ and $f_{B_s}$ given in Table 2 show a 10% increase compared to the quenched values (see also Fig. 1). We do not resolve any sea quark mass dependence. The dependence on the value of $\alpha_s$ is weaker than for the plaquette gauge action, and the difference between renormalized and bare decay constants is only about 5%.

In Fig. 1 we show the one-loop corrections to the current $J_4$ as a function of the heavy-light meson mass. In the $B$ region, $1/M \sim 0.2$, we find the correction to $J^{(1)}_{4,lat}$ to be very small and the two other terms to contribute about the same amount. The $J^{(2)}_{4,lat}$ contribution also contains a discretization correction to the current first pointed out in [2]. We note that this discretization correction is considerably smaller for the RG gauge action than for the plaquette gauge action [3].

For $f_{B_s}/f_B$, we cannot resolve a difference between the three lattices.

In a parallel study of B mesons using clover heavy quarks [5], we have obtained $f_B$ and $f_{B_s}$ taking the chiral limit for sea quark at $\beta = 1.8, 1.95$ and $2.1$. The results from that study at $\beta = 1.95$ agree within the estimated errors with the present results from NRQCD.

## 4. Spectrum

In Fig. 2, we give our results for several $B$ splittings from the lattices with $n_f = 0$ and $n_f = 2, \kappa_{sea} = 0.1375$. The top part of the figure shows the $B^* - B$ splitting. At present, we cannot resolve any unquenching effects. For quarkonia, on the same lattices, the hyperfine splitting is found to increase from the quenched value only by a few MeV [6]. We find the $B^* - B$ splitting to be $\sim 30\%$ smaller than the experimental value. Possible sources of systematic error are the finiteness of the sea quark mass, the $O(\alpha)$ correction to the coefficient of the $\sigma \cdot B$ operator, and higher order relativistic corrections.

In the middle part of Figure 2, we show results for the $B^*_2 - B$ splitting, and in the lower part, the spin-averaged $\Lambda_b - \overline{B}$ splitting. We do not find significant unquenching effects. However, for definite conclusions, we need to study several sea quark masses and lattice spacings, which is in progress.

This work is supported in part by the Grants-in-Aid of Ministry of Education, Science and Culture (Nos. 09304029, 10640246, 10640248, 10740107, 11640250, 11640294, 11740162). SE and KN are JSPS Research Fellows. AAK and TM are supported by the Research for the Future Program of JSPS.

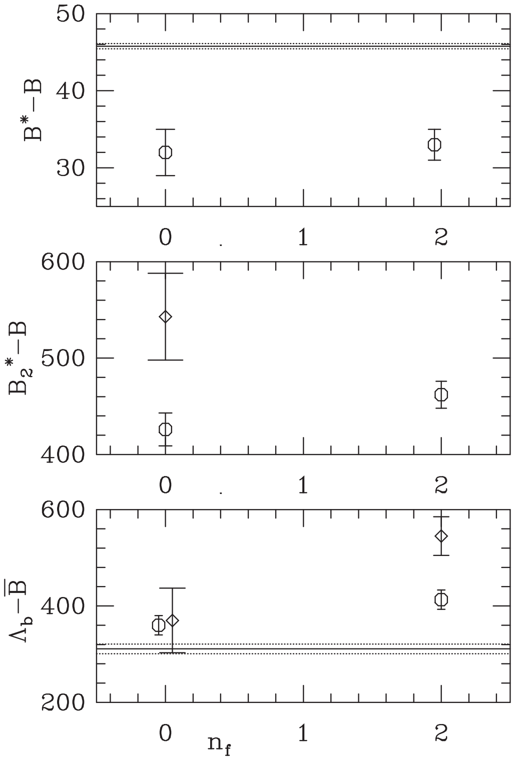


Figure 2. Meson and baryon splittings in MeV. Circles denote results from CP-PACS at $a^{-1}(\sqrt{\sigma}) \simeq 0.9$ GeV. Diamonds stand for results from [7] (quenched) and [8] ($n_f = 2$). Only statistical errors are shown. The solid line denotes the experimental value, the dashed lines, its error.

## REFERENCES


1. R. Burkhalter, Nucl Phys. **B** (Proc. Suppl.) **73** (1999) 3.
2. C. J. Morningstar and J. Shigemitsu, Phys.Rev. D57 (1998) 6741.
3. K.-I. Ishikawa, these proceedings.
4. J. Hein *et al.*, Nucl. Phys. **B** (Proc. Suppl.) **73** (1999) 366.
5. H.P. Shanahan *et al.*, CP-PACS collaboration, these proceedings.
6. T. Manke *et al.*, CP-PACS collaboration, these proceedings.
7. A. Ali Khan *et al.*, hep-lat/9809140.
8. S. Collins *et al.*, hep-lat/9901001.